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Methods for Assessing Effects of Timber Harvest on Small Streams

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ABSTRACT

The methods used by the Northwest and Alaska Fisheries Center's Auke Bay Laboratory in assessing the effects of clear-cut logging on salmonid habitat and the effectiveness of buffer strips in protecting fish habitat during and after logging are described in detail. The methods have been used by the Laboratory since 1982 to study fish populations and habitat in three different categories of streams in southeastern Alaska: streams in clearcuts that had timber removed along one or both banks, streams in clearcuts that had a buffer strip of timber along one bank and undisturbed old-growth forest along the other, and streams in mature, undisturbed forest. The methods described include measurements of fish, periphyton, benthos, preferred fish habitats, and stream physical characteristics, such as discharge, gradient, substrate, and water quality. Measurements collected by two teams, each independently measuring habitat characteristics of the same sections of a test stream, were similar; thus, the methods give reproducible data.

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Since 1982, the Northwest and Alaska Fisheries Center's Auke Bay Laboratory (ABL) has been determining effects of clear-cut logging on salmonid habitat and assessing effectiveness of buffer strips in protecting salmonid habitat, particularly streams with coho salmon (Oncorhynchus kisutch), during and after logging. Buffer strips, strips of streamside trees, are left along one or both stream banks to protect fish habitat.

Knowledge of rearing habitat and fish populations in the stream must be acquired before effects of habitat alteration can be assessed. Components of salmonid habitat important to rearing fish include width, depth, velocity, and discharge of the stream; gradient and stability of the channel; composition of the substrate; amount of canopy cover, undercut banks, and large organic debris; and water quality (Reiser and Bjornn 1979). Changes in these components may alter growth, survival, and density of the fish population. For example, after streamside vegetation is removed, water temperature may increase in summer but decrease in winter (Chapman 1962; Hall and Lantz 1969; Narver 1972). Water temperature, in turn, influences growth of fish, their ability to capture and use food, and their ability to withstand disease (Baldwin 1956; Reiser and Bjornn 1979). Changes in habitat can also change abundance of benthic invertebrates and thus influence the amount of food available to fish (Murphy et al. 1981). Increased solar radiation from canopy removal associated with logging can increase aquatic production at all trophic levels by increasing periphyton production (Murphy and Hall 1981). Clearcutting to the stream bank reduces pool habitat and cover because undercut banks collapse and large organic debris may be removed (see Murphy and Hall 1981; Bryant 1983; Tschaplinski and Hartman 1983 for details).

This paper describes methods we used in an extensive evaluation of buffer

strips on second- to fourth-order streams (Strahler 1957). Although the methods were designed primarily for logging studies, they may be applicable to other studies involving fish populations and habitat in small streams. We also determined the reproducibility of the methods.

EXPERIMENTAL DESIGN

We used a two-way classification and the extensive post-treatment approach of Hall et al. (1978) to evaluate effects of logging on reaches of streams at six locations in southeastern Alaska (Fig. 1). At each location, three experimental streams were sampled: a buffered stream (a stream with a buffer strip), a clear-cut stream (a stream logged to one or both banks), and a control stream in an undisturbed old-growth forest. The three streams at each location were similar in order (Strahler 1957), gradient, discharge, and, for logged streams, date the timber was harvested (1-12 yr before the study).

Each experimental stream was divided into three sections: lower, middle, and upper. In each section, a 30-m long reach was randomly selected and sampled. The same reach was sampled in both summer (June-August) and winter (February-March). The study design, therefore, consisted of 6 replications of 3 streams, each stream with 3 reaches, for a total of 54 reaches on 18 streams.

HABITAT CHARACTERISTICS

Transect Measurements

During summer, 11 linear transects perpendicular to streamflow were established at 3-m intervals in each 30-m reach because accurate measurement of habitat characteristics requires use of transects (Platts et al. 1983). At each transect, a tape was stretched over the stream channel, and these

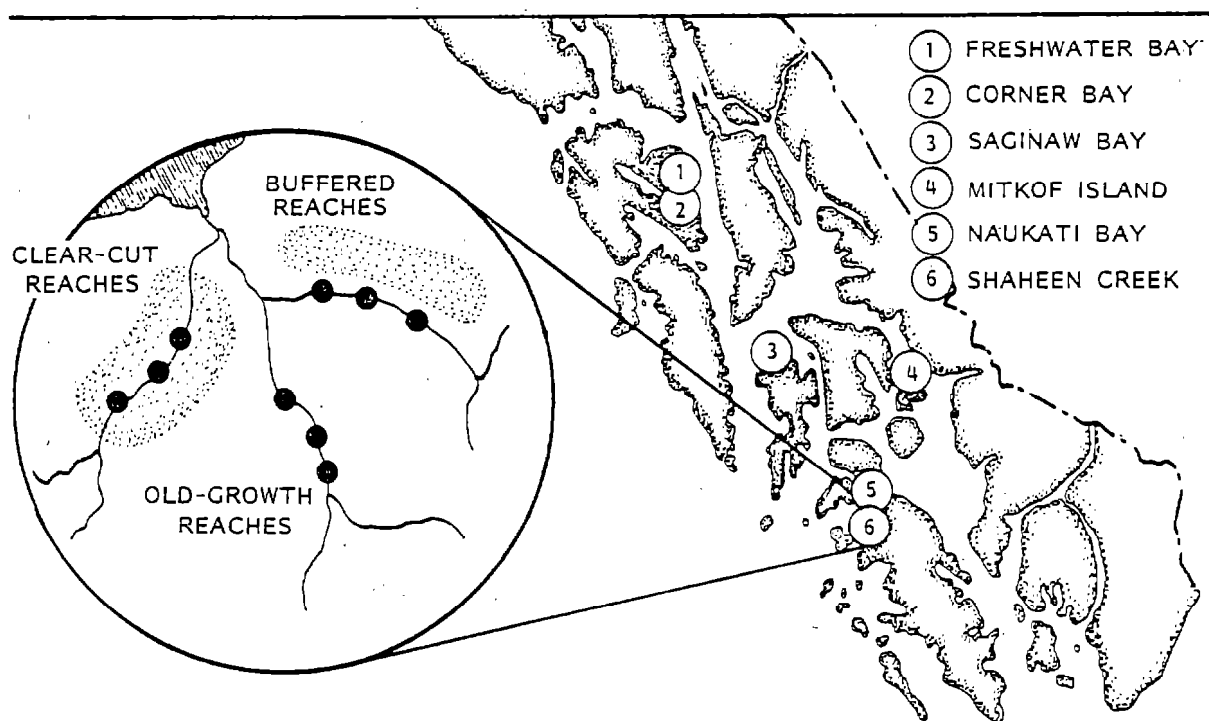


Figure 1. --Six study sites in southeastern Alaska and experimental groups at each site.

measurements were taken: stream width (water width) and channel width (distance between annual highwater marks on each bank) to the nearest 0.1 m; water depth to the nearest centimeter at 0.25, 0.50, and 0.75 of the stream width; and width of each substrate type and habitat type to the nearest 0.1 m. Substrate was classified according to the size and type of material on the stream bottom (Table 1). Habitat types were qualitatively divided into riffles, pools, and glides, depending upon surface turbulence, depth, and current velocity (Bisson et al. 1982). Riffles are shallow areas with moderate to fast currents and surface turbulence. Pools are characterized by deeper water with low to moderate current velocities (i.e., depressions caused by scouring or quiet areas behind channel obstructions). Glides are areas of even laminar flow over fine-grained substrate, often at transition zones between pools and riffles.

Table 1. --Size classification of different substrate types (adapted from Platts et al. 1983).

Substrate	Size (diameter)
Sand	<2 mm
Gravel	2-64 mm
Small cobble	65-128 mm, 2.5-5 in.
Cobble	129-255 mm, 5-10 in.
Boulder	>255 mm, >10 in.
Bedrock	
Fine particulate organic matter	<1 mm
Coarse particulate organic matter	1-100 mm
Large organic debris	>100 mm

In winter, new transects were established in each reach to measure stream width and the amount of ice on the stream surface and bottom. Ice was classified as anchor ice or surface ice (Benson 1973). Anchor ice forms on the bottom of the stream and grows outward. Surface ice is suspended on the surface in sheets. At the 0-, 10-, 20-, and 30-m transects, thickness of ice,

snow depth on one bank, and snow depth on surface ice were measured to the nearest centimeter.

Total wetted area (m^2) for each 30-m reach was calculated by multiplying the average width of the reach by its length. Percent habitat types, substrate types, and ice types were calculated from measurements on the transects:

$$x_i = \frac{\sum_{j=1}^n H_{ij}}{\sum_{j=1}^n T_j} \times 100,$$

where

- x_i = percent habitat type i , substrate type i , or ice type i ;
- H_{ij} = width of habitat type i , substrate type i , or ice type i of transect j ;
- T_j = width of transect j ; and
- n = number of transects.

Large Organic Debris

In summer, we measured the volume of each piece of large organic debris in each reach; that is, any woody item (logs, tree limbs, rootwads) ≥ 10 -cm diameter and ≥ 1 -m long in the stream channel. Volume of rootwads was measured separately; volume of logs and branches was estimated by measurement of length (L) to the nearest 0.1 m and diameter (D) of each end to the nearest centimeter (Fig. 2a). If a log was partially embedded in the substrate, we obtained a diameter nearest the point where the log entered the substrate. Volume (V) was estimated by the Smalian formula: $V = (D_1^2 + D_2^2)L/8$ (Bryant 1982). Volume of rootwads was calculated from measurements, of base diameter,

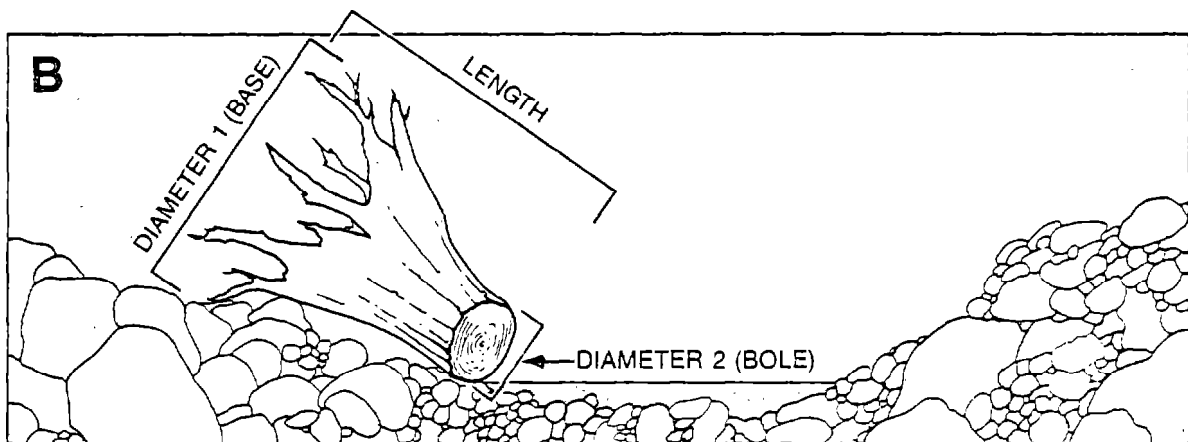
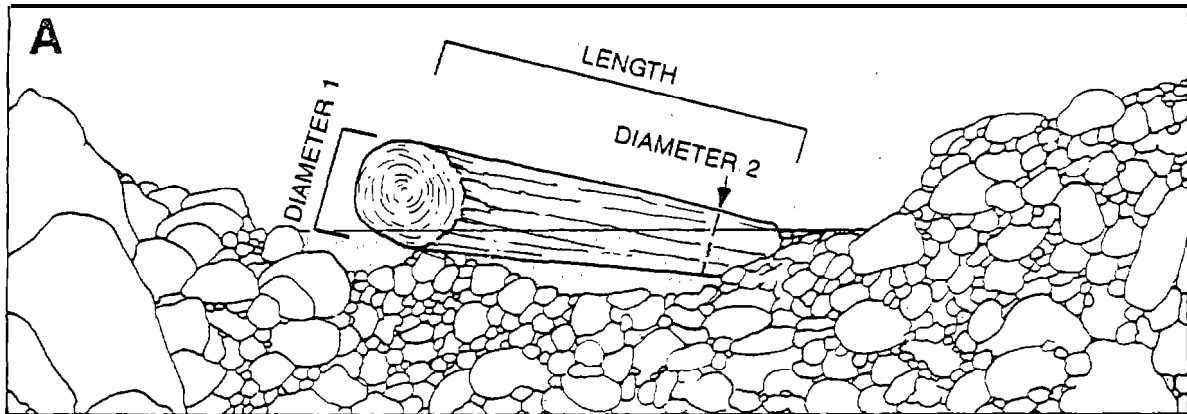


Figure 2.--Large organic debris measurements: A) Log and B) rootwad.

bole diameter, and length (Fig. 2b) with the formula for the frustum of a cone (Hodgman 1962):

$$V = \frac{h}{3}\pi(r_1^2 + r_1r_2 + r_2^2),$$

where

h = length of rootwad (distance from base to 'where bole starts to parallel stem),

r_1 = radius of base, and

r_2 = radius of bole.

Total volume of large organic debris in a reach was determined by summing the volume of individual pieces. Large organic debris volume was then standardized by dividing by the area of the reach. Measurement of each piece of large organic debris was often time consuming and may be accomplished more efficiently by aerial photography or other photographic techniques (Bishop 1968).

Undercut Banks

In summer, we measured the area of each undercut bank >50 cm long and >20 cm wide (the amount overhanging the water) in each reach. Length of the undercut was measured to the nearest 0.1 m, and width to the nearest centimeter at three locations equidistant along the length of the undercut. Area of the undercut bank was then calculated by multiplying average width by length. Total undercut bank area in a reach was determined by summing the area of individual undercut banks and then standardized by dividing by the area of the reach.

Stream Discharge

Stream discharge, defined as the volume of water moving past a given cross-section of stream per unit of time, was measured during summer and winter in an area of each reach that had fine-grained substrate and laminar flow. If a suitable area was not found within the reach, an area close to the reach was chosen. Stream width (w) was measured to the nearest 0.1 m, perpendicular to the direction of flow. To account for variations in velocity with width, the stream was broken into three to five sections. The discharge calculation was based on the sum of the discharges for the individual sections. A portable water-current meter (Marsh-McBirney Model 201¹) and a meter stick were used to measure velocity and depth in each section. Velocity (v) at 0.4 of stream depth (measured from stream bottom) was measured to the nearest 0.015 m/s (0.05 ft/s). Depths (d) were measured to the nearest centimeter. Discharge (Q) was calculated by the following equation (Platts et al. 1983):

$$\sum_{i=1}^n (w_{i+1} - w_i) [(d_i + d_{i+1})/2] [(v_i + v_{i+1})/2] ,$$

where,

n = the total number of individual sections,

w = horizontal distance from the initial point,

d_i = water depths for each section, and

v_i = measured velocity for each section.

Water depth and velocity at distances w_i and w_n (the stream banks) are always 0. We also subjectively estimated stream stage (low, medium, or high) and discharge of any tributaries entering the reach.

¹ Reference to a trade name does not imply endorsement by the National Marine Fisheries Service, NOAA;

Gradient _I

Stream gradient, the change in elevation of the surface water per each 30 m of stream channel, was measured in each reach in the summer. At the downstream transect (0 m), a hand level (Lietz, 5X) on top of a meter stick was used to sight to a meter stick at the upstream transect (30 m) to determine change in elevation. Gradient was taken in an area of each reach with the fewest obstructions (e.g., branches), which allowed easy sighting with the hand level.

Canopy Density

Percent canopy density over each reach was determined in, summer and winter with a spherical canopy densiometer. A densiometer is a convex mirror divided into square grids with four equally spaced dots in each grid (Lemmon 1956). Canopy density was estimated with the instrument by counting dots covered by overhead canopy. Readings were taken from the middle of the stream at the 0-, 10-, 20-, and 30-m transects. Four separate readings were taken at each transect facing north, east, south, and west. Percent canopy density in each reach was calculated by dividing the sum of all covered dots by the total number of possible dots (1,536) and multiplying by 100.

Channel Stability

Stream channel stability, a measure of the resistance of a stream to erosion, provides information on how well the stream will adjust to and recover from changes in flow or sediment transport. Channel stability in each reach was qualitatively analyzed in summer according to the guidelines of Pfankuch (1975) (Fig. 3).

Figure 3.--Channel stability form (Pfankuch 1975).

R-1 STREAM REACH INVENTORY and CHANNEL STABILITY EVALUATION

REACH LOCAT _____ Survey Date _____ Time _____ Obs. _____

Forest _____ Agr. Dist. _____
P.W.I. _____

Stream _____ W/S No. _____

Reach Description &
Other Identification _____

Key #	Stability Indicators by Classes (Fair and Poor on reverse side)	
	EXCELLENT	GOOD
1	Bank slope gradient < 30%.	(2) Bank slope gradient 30-40%.
2	No evidence of past or any potential for future mass wasting into channel.	(3) Infrequent and/or very small. Mostly healed over. Low future potential.
3	Essentially absent from immediate channel area.	(2) Present but mostly small twigs and limbs.
4	90%+ plant density. Vigor and variety suggests a deep, dense, soil binding, root mass.	(3) 70-90% density. Fewer plant species or lower vigor suggests a less dense or deep root mass.
5	Ample for present plus some increases. Peak flows contained. W/D ratio < 7.	(1) Adequate. Overbank flows rare. Width to Depth (W/D) ratio 8 to 15.
6	65%+ with large, angular boulders 12"+ numerous.	(2) 40 to 65%, mostly small boulders to cobbles 6-12".
7	Rocks and old logs firmly embedded. Flow pattern without cutting or deposition. Pools and riffles stable.	(2) Some present, causing erosive crown currents and minor pool filling. Obstructions and deflectors newer and less firm.
8	Little or none evident. Infrequent raw banks less than 6" high generally.	(4) Some, intermittently at outcrops and constrictions. Raw banks may be up to 12".
9	Little or no enlargement of channel or point bars.	(4) Some new increase in bar formation, mostly from coarse gravels.
10	Sharp edges and corners, plane surfaces roughened.	(1) Rounded corners and edges, surfaces smooth and flat.
11	Surfaces dull, darkened, or stained. Gen. not "bright".	(1) Mostly dull, but may have up to 35% bright surfaces.
12	Assorted sizes tightly packed and/or overlapping.	(2) Moderately packed with some overlapping.
13	No change in sizes evident. Stable materials 80-100%.	(4) Distribution shift slight. Stable materials 50-80%.
14	Less than 5% of the bottom affected by scouring and deposition.	(6) 5-30% affected. Scour at constrictions and where grades steepen. Some deposition in pools.
15	Abundant. Growth largely moss-like, dark green, perennial. In swift water too.	(1) Common. Algal forms in low velocity & pool areas. Moss here too and wetland waters.

EXCELLENT COLUMN TOTAL _____ GOOD COLUMN TOTAL _____

Add values in each column and record in spaces below. Add column scores.
E. _____ + C. _____ + F. _____ + P. _____ = Total Reach Score.

Adjective ratings: < 30-Excellent, 30-76-Good, 77-114-Fair, 115+-Poor*
*(Scores above may be locally adjusted by Forest Hydrologist)

RI-Form 2500-5A Rev. 1-75 Side 1.

Side 2

INVENTORY DATA: (observed or measured on this date)

Stream Width _____ ft. X Ave. Depth _____ ft. X Ave. Velocity _____ f/c* _____ cfs

Reach _____ Stream _____ Turbidity _____ Stream _____ Sinuosity _____

Gradient _____ % Order _____ Level _____ Stage _____ Ratio _____

Temperature _____ of _____ or C of _____ Air _____ Water _____ Others _____

Key #	Stability Indicators by Classes	
	FAIL	POOR
1	Bank slope gradient 40-60%.	(6) Bank slope gradient 60%+.
2	Moderate frequency & also, with some raw spots eroded by water during high flows.	(9) Frequent or large, causing sediment nearly yearlong OR imminent danger of same.
3	Present, volume and size are both increasing.	(6) Moderate to heavy amount, predominantly larger sizes.
4	50-70% density. Lower vigor and still fewer species form a somewhat shallow and discontinuous root mass.	(9) < 50% density plus fewer species & less vigor indicate poor, discontinuous, and shallow root mass.
5	Barley contains present peaks. Occasional overbank floods. W/D ratio 15 to 25.	(3) Inadequate. Overbank flows common. W/D ratio > 25.
6	20 to 40%, with most in the 3-6" diameter class.	(6) < 20% rock fragments of gravel sizes, 1-3" or less.
7	Moderately frequent, moderately unstable obstructions & deflectors move with high water causing bank cutting and filling of pools.	(6) Frequent obstructions and deflectors cause bank erosion yearlong. Sediment traps full, channel migration occurring.
8	Significant. Cuts 12"-24" high. Root mat overhangs and elongating evident.	(12) Almost continuous cuts, some over 24" high. Failure of overhangs frequent.
9	Moderate deposition of new gravel & coarse sand on old and some new bars.	(12) Extensive deposits of predominantly fine particles. Accelerated bar development.
10	Corners & edges well rounded in two dimensions.	(3) Well rounded in all dimensions, surfaces smooth.
11	Mixture, 50-50% dull and bright, ± 1% ie. 35-65%.	(3) Predominantly bright, 65%+ exposed or accreted surfaces.
12	Mostly a loose assortment with no apparent overlap.	(6) No packing evident. Loose assortment, easily moved.
13	Moderate change in sizes. Stable materials 20-50%.	(12) Marked distribution change. Stable materials 0-20%.
14	30-50% affected. Deposits & scour at obstructions, constrictions, and bends. Some filling of pools.	(18) More than 50% of the bottom in a state of flux or change nearly yearlong.
15	Present but spotty, mostly in backwater areas. Seasonal blooms make rocks slick.	(3) Perennial types scarce or absent. Yellow-green, short term blooms may be present.

FAIL COLUMN TOTAL _____ POOR COLUMN TOTAL _____

Size Composition of Bottom Materials (Total to 100%)

1. Exposed bedrock, _____ %	5. Small rubble, 3"-6" _____ %
2. Large boulders, 3"+ Dia. _____ %	6. Coarse gravel, 1"-3" _____ %
3. Small boulders, 1-3" _____ %	7. Fine gravel, 0.1-1" _____ %
4. Large rubble, 6"-12" _____ %	8. Sand, silt, clay, suck. _____ %

Water Quality

Dissolved oxygen, pH, and total alkalinity were measured in the field with a Hach kit. In the summer, water samples were collected at or near the center of flow from smooth flowing, unbroken areas nearest the downstream end of the lower reach. All water samples were taken before minnow traps were placed in the reach. Dissolved oxygen was determined by the azide modification method (APHA 1971), total alkalinity was determined by the methyl orange indicator method (APHA 1971), and pH was determined by the calorimetric method (Klein 1959).

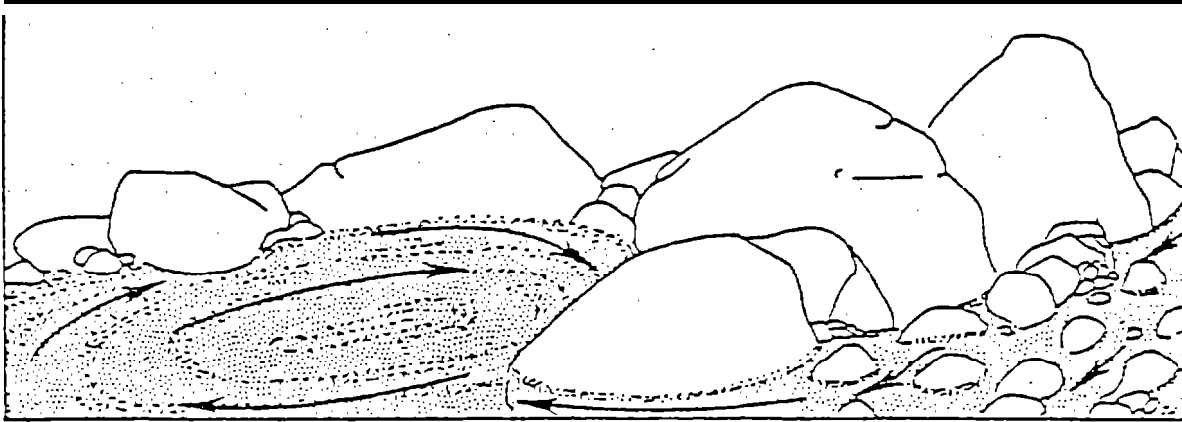
Air and-water temperature were measured to the nearest 0.1°C with a handheld precision thermometer. Air temperature was measured in the shade with a dry thermometer; water temperature was measured in a shaded area of moderate current. Both air and water temperatures were taken immediately upon arrival at each reach and at random times throughout the day.

Pool Types and Volume

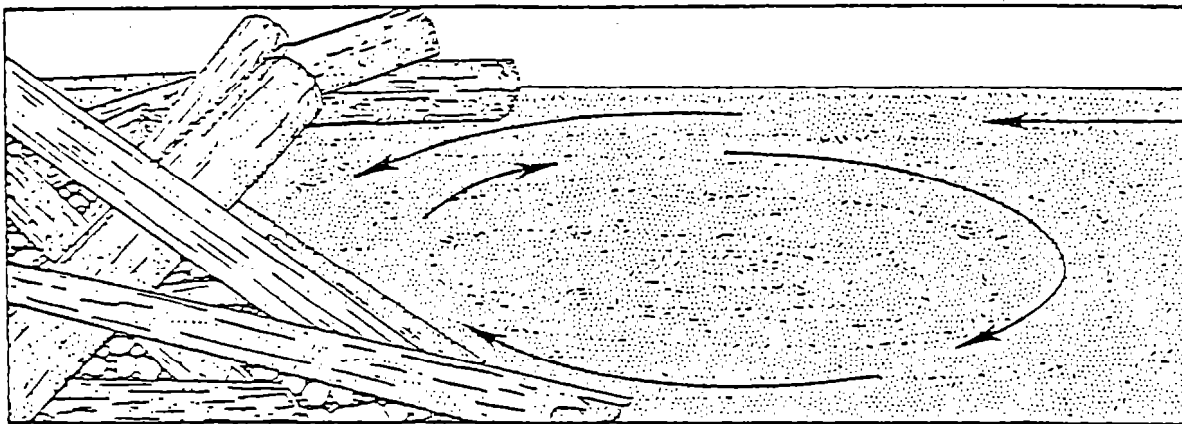
In summer, for each reach, we classified pool type (Table 2; Fig. 4), measured pool volume, and noted whether the pool was formed by large organic debris or nondebris (i.e., boulders, bedrock, and sediment bars). Pool volume was determined by measuring length and width to the nearest 0.1 m and five depths to the nearest centimeter. Depth was measured at the center of the pool and at two locations along each axis (length and width) equidistant from the center and margin of the pool. Volume was calculated by multiplying mean depth by the length and width of the pool. Unusually shaped or large pools were divided into two sections, and separate volumes were determined for each section. Pool volumes were standardized by dividing by the reach area.

Table 2.--Classification of pool types and their formation (all but upsurge pools adapted from Bisson et al. 1982).

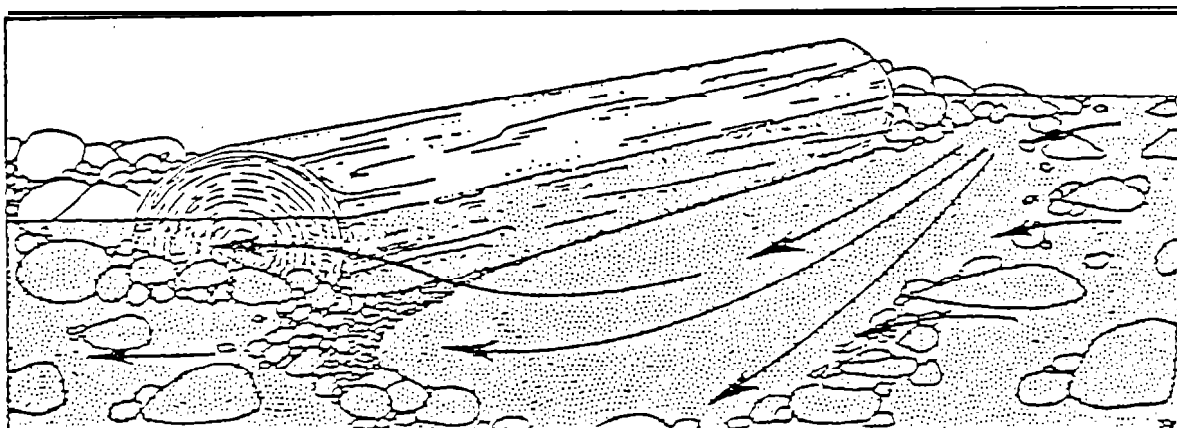
Pools	Formation
Backwater	Quiet area behind obstructions, such as channel bars and debris. Very low current velocities.
Lateral - scour	Depressions in streambed formed as flow is deflected to one side of stream by channel obstructions causing scouring.
Plunge	Flow drops vertically over channel obstruction causing scouring.
Secondary channel	Pockets of water that remain in overflow channels after water recedes following freshets.
Dammed	Flow impounded upstream from a complete or nearly complete channel blockage (i.e., debris jams).
Upsurge	Flow forced under channel obstruction causing scouring.
Trench	Formed as long, deep slots in a stable substrate usually flanked by bedrock walls. The fastest stream velocity of any pool type.



Backwater pool associated with boulders.

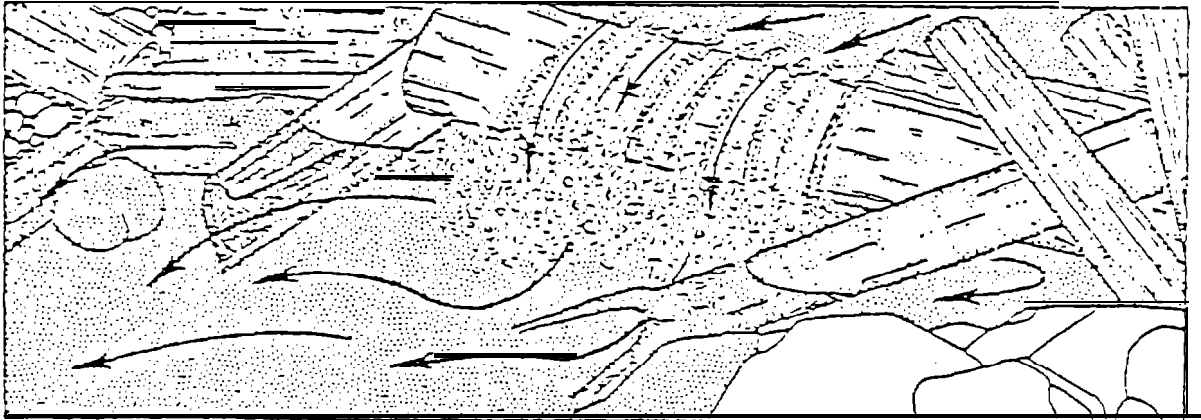


Dammed pool associated with large debris.

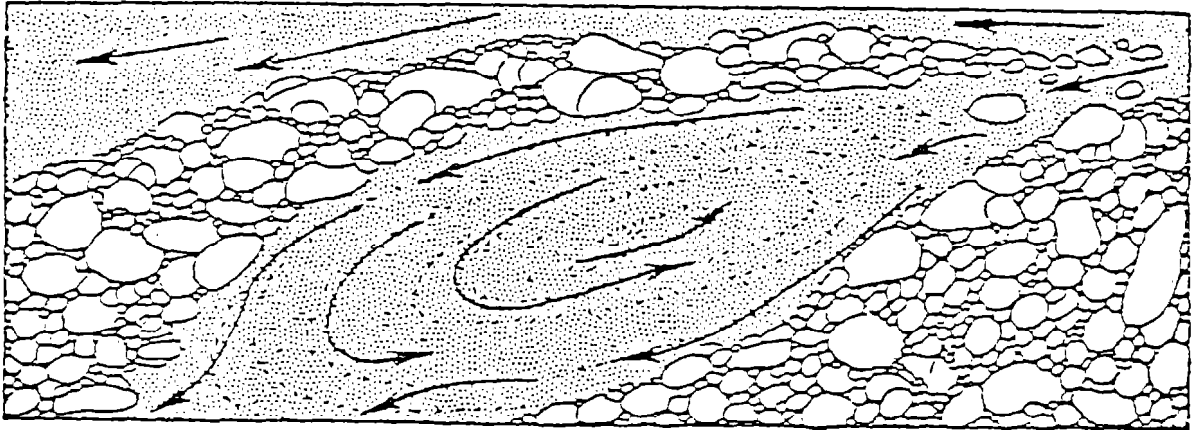


Lateral scour pool associated with large debris,

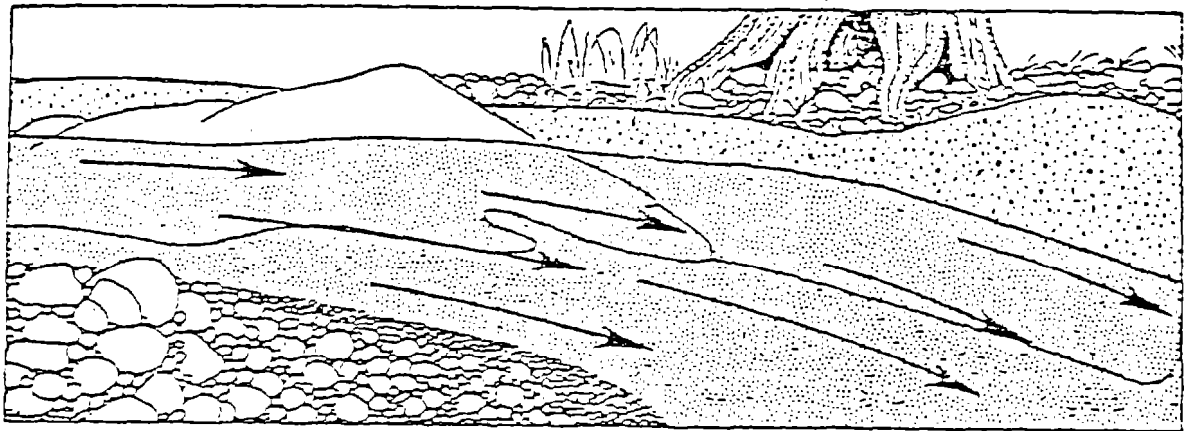
Figure 4.--Types of pools (adapted from Bisson et al. 1982).



Plunge pool associated with large debris.

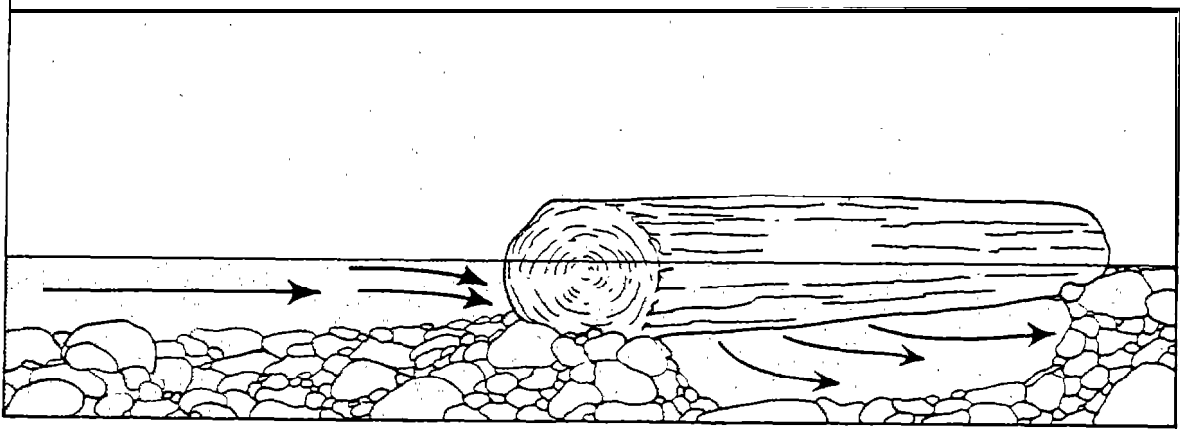


Secondary channel pool.



Trench pool associated with bedrock.

Figure 4 .--Continued.



Upsurge pool associated with large debris.

FISH POPULATION CHARACTERISTICS

Population Density in Summer and Winter

Size of fish populations in each reach was estimated by single-census mark-recapture (Ricker 1975). Guidelines in Robson and Regier (1964) were used to determine the minimum number of fish to mark, recapture, and examine for marks so that population estimates would not depart from the true population size by more than 25%, 95% of the time,

Block nets (11-m long, 1.2-m wide, 0.3-cm mesh) were set at the downstream and upstream ends of each reach. Gee minnow traps (45.5-cm long, 0.32-cm mesh), seines (4.5-m-long, 1.2-m-wide, 0.6-cm mesh), and gas-powered electroshockers (Smith-Root, Type XV) were used to capture fish for marking. Minnow traps baited with boraxed salmon eggs were used first. Ten or more traps were set throughout the reach (usually in pools) and left undisturbed for at least 1 h. Because minnow traps are size selective (Bloom 1976), fish captured in them represent only a portion of the total-fish population. In summer, minnow traps were most effective for capturing parr (age 1 and older), especially in pools. In winter, minnow traps were effective in capturing both fry (age 0) and parr but had to be fished longer (12-24 h) than in summer. Consequently, catches from minnow traps were supplemented with catches from seines and electroshockers. Seines were effective in summer for capturing fry in areas with little debris; electroshockers were effective in both summer and winter for collecting fish but were difficult to use in pools deeper than 2 m and in areas with large amounts of debris.

Captured fish were anesthetized with MS-222 and marked. Salmonids were marked by removal of the tip of either the dorsal or ventral lobe of the caudal fin. These two marks were alternated between reaches. Cottids (Cottus spp.) were marked by removal of part of a pelvic fin. After the fish recovered,

from the anesthetic, they were distributed throughout the reach. One hour later, following recommendations of Peterson and Cederholm (1984), the fish were recaptured with electroshockers (summer and winter) and seines (summer). Minnow traps were not effective in recapturing fish.

Population estimates were made for fry (age 0) and parr (> age 1) of each salmonid species and for cottids. Chapman's version of the Petersen estimate was used to compute population estimates (N) (Ricker 1975):

$$\hat{N} = \frac{(M + 1)(C + 1)}{(R + 1)} - 1,$$

where

M = number of marked fish (mark sample),

C = number of fish examined for marks, and

R = number of recaptured marked fish.

Ninety-five percent confidence limits were computed for each population estimate according to recommendations in Seber (1973) and using the charts and tables in Pearson and Hartley (1966) and Adams (1951). To standardize population estimates, we used area of each reach during a low flow to estimate fish density (no./m²).

Growth and Age Composition in Summer and Winter

In early summer, salmonid fry are easily distinguished from parr because fry are much smaller, brighter, and have proportionately larger fins and

smaller eyes (Crone and Bond 1976). In late summer and winter, however, fry and parr must be differentiated by length-frequency and scale analysis because they have similar size and morphological characteristics.

In summer, lengths and weights were collected from fish to establish length-frequency histograms and length-weight regressions. Data for all three reaches in each stream were combined to establish these relationships. In each reach, we measured fork length of all salmonid Parr, 25 randomly selected salmonid fry of each species, and 25 randomly selected cottids. Length and corresponding weight measurements were taken from 6 fry and 12 parr for each salmonid species and from 12 cottids. Fork length was measured to the nearest millimeter, and weight to the nearest 0.1 g. Fish for length-weight measurements were selected to cover the range of sizes in the population (Ricker 1975). Length-weight regressions were used to estimate the weight of fish on which only length was measured. Biomass (g/m^2) for each species and age group was computed by multiplying mean weight by density.

Scales were also collected from the 12 coho salmon parr and 12 trout (Salmo spp.) parr that had been measured for length and weight. Scales were not collected from Dolly Varden (Salvelinus malma) Parr. Eight to ten scales were removed from the left side of the fish below the posterior end of the dorsal fin and 2-3 rows of scales above the lateral line. Scales were placed on a frosted glass slide and then covered with a clear slide. Because few fish were captured in winter and fry and parr were often difficult to separate, all captured fish were measured (fork length), and scales were collected from 15 trout and 15 coho salmon that were intermediate in size and larger. In winter, weights were not measured.

To save time in winter, an alternate method was used to collect scales. Scales from each fish were smeared on a strip of clear acetate (2.5 cm x 7.5 cm), which was then folded in half and squeezed to separate the scales. The strip was placed in a coin envelope. In the subsequent scale analysis, we did not find any advantage of glass slides over this method. The clear-acetate method was quicker in the field and, therefore, most efficient.

Scale images were projected with a Leitz microprojector (120X), and ages were assigned to each fish after interpretation of scales by at least two investigators. The percent of each age among fish of a given length was used to convert the length-frequency distributions to age composition (Ricker 1975).

Habitat Selection

In winter, we quantified the preferred habitat of juvenile salmonids by counting the fish in each pool, riffle, and glide during collection of the mark sample for population estimates. First, several baited-minnow traps were placed in each habitat unit and fished for at least 1 h. Several traps were set to ensure that movement of fish between habitat units was minimal. After the traps were retrieved, we captured the remaining fish with electroshockers. During winter, most fish were under cover and probably did not move between habitat units during sampling.

For each habitat unit (i.e., individual pools, riffles, or glides), we measured surface area and area of cover (total area of large organic debris, undercut banks, and cobble substrate), maximum depth, and minimum and maximum temperature. Habitat utilization by species and age group in each habitat

unit was calculated relative to habitat area according to the equation of Bisson et al. (1982):

$$U_{ij} = \frac{D_{ij} - D_t}{D_t},$$

where

U_{ij} = utilization of habitat unit j of type i (seven pool types listed in Table 2, plus riffles and glides),

D_{ij} = total catch in habitat unit j of type i divided by surface area of habitat unit j , and

D_t = total catch in entire study reach divided by surface area of study reach.

This electivity index relates abundance in a habitat unit to the abundance in the study area. Calculated values theoretically range from -1, total avoidance of a habitat unit, to +1 as the proportion of a population residing in an individual habitat unit increases. Values near 0 indicate the population was found in a particular habitat unit in proportion to the area of that habitat unit in the reach (Bisson et al. 1982).

Habitat preference (U_i) by species and age group equalled the mean utilization of all habitat units of type i :

$$U_i = (\sum_{j=1}^n U_{ij})/n.$$

BENTHOS AND FISH DIET

In summer, benthic samples from four different riffles in each reach were collected with a modified Hess sampler (Fig. 5). At each riffle, the sampler

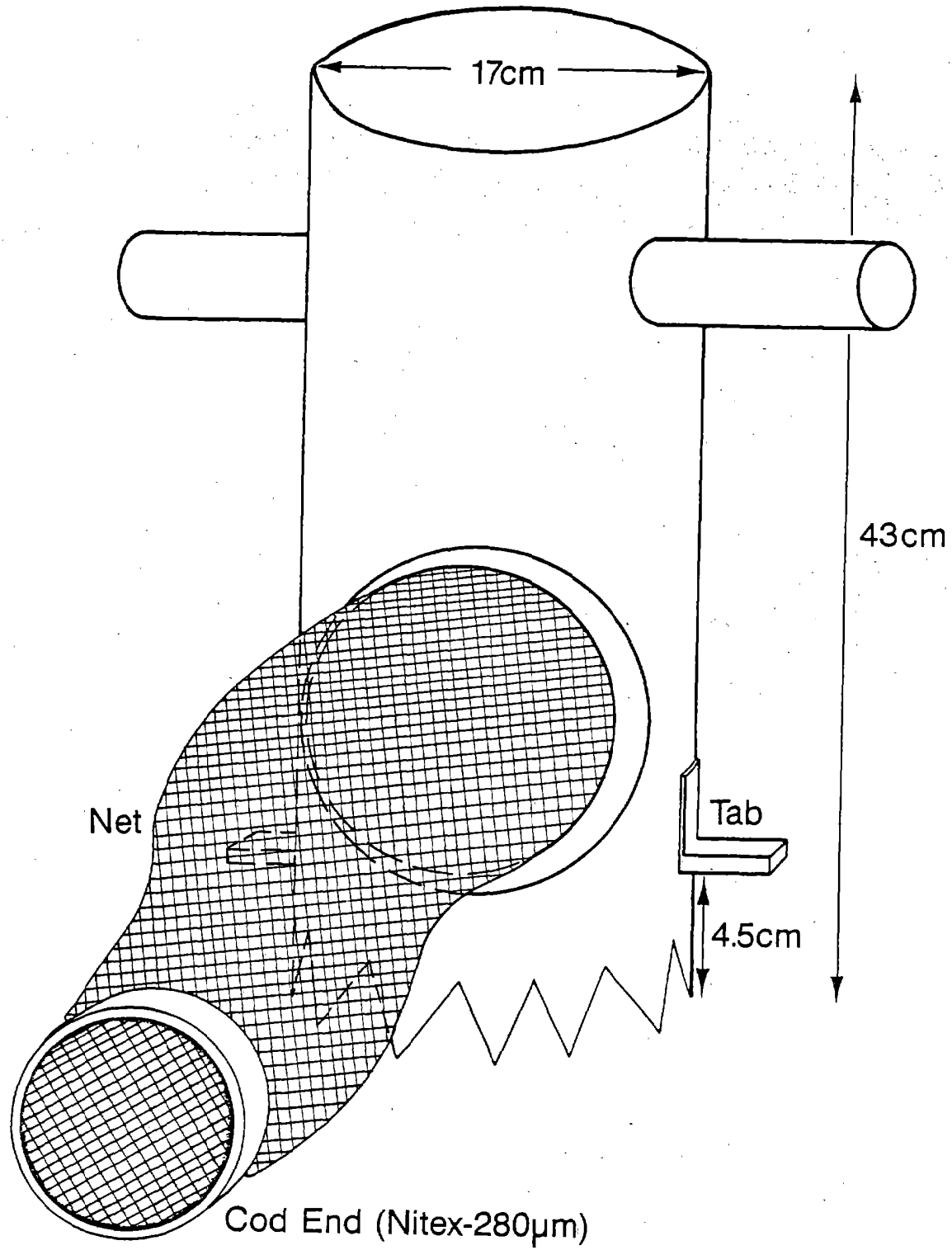


Figure 5.--Modified Hess benthic sampler.

was pushed 5 cm into the substrate. Samples were vigorously swirled to dislodge invertebrates from the substrate, decanted through Nitex netting (280 μm), and preserved in 10% Formalin. Benthos biomass (g/m^2) was determined on a wet-weight and dry-weight basis as the mean of the four samples.

To correlate food availability in the stream to food consumed by juvenile coho salmon, we examined stomach contents of the fish and determined the abundance of benthic invertebrates. Ten coho salmon (five fry and five Parr) were collected above the upper block net of each sampled reach by electrofishing. Thus, the stomachs did not contain foods dislodged by the field crew. We anesthetized the fish with MS-222, cut their abdomens with a scissors, and preserved the fish in 10% Formalin. In the laboratory, stomachs were removed, and the invertebrates in them sorted and identified to family in all cases and to genus and species when possible.

PERIPHYTON

A cobble approximately 12 cm in diameter was randomly selected from each riffle sampled for benthos (a total of four samples from each reach). Each cobble was scraped with a wire brush, and periphyton rinsed into a bucket. Samples were preserved with 5% Formalin. The average width, length, and depth of each rock were recorded.

Periphyton was allowed to settle, the supernatant decanted, and the remaining slurry transferred to a crucible for drying (48 h, 60°C) and burning (8 h, 550°C). Biomass of periphyton was expressed as milligrams AFDW (ash-free dry weight) per one-half the calculated surface area of each cobble. Biomass of periphyton in a reach was reported as the mean of the four samples.

STATISTICAL ANALYSES

The experimental design followed a two-way classification, and each reach was classified by the treatment (buffered, clear-cut, or old-growth) and the replication (site/location) to which it belonged. Effects of treatments on fish population characteristics and habitat variables were then analyzed by two-way analysis of variance (ANOVA) with treatments as one factor and replications as the other factor (Snedecor and Cochran 1967).

Lack of data on pre-treatment conditions forced us to assume that there was no difference between streams in a replication before logging (treatment). If streams differed systematically in size or gradient, our assumption may be weak. For example, clear-cut streams in our study were generally smaller than old-growth or buffered streams. In this case, analysis of covariance was used with stream discharge as a covariate in conjunction with the two-way ANOVA to account for differences in stream size.

To determine which relationships between fish populations and habitat were important, we used a combination of factor analysis and multiple regression. Because we measured many habitat variables that had significant correlations, principal component analysis was used to reduce the data to a small number of uncorrelated principal components that could then be related to fish population characteristics by multiple regression. In the first step, the habitat data, including both physical variables and biological variables (i.e., benthos and periphyton), were factored, and the extracted principal components were rotated for interpretation (SPSS, Nie et al. 1975). In the second step, density or biomass of each fish species was regressed on the principal factors by stepwise multiple regression (SPSS, Nie et al. 1975) to

determine the most important habitat features for each species. Habitat variables were entered in order of highest partial correlation with the dependent fish variable until a maximum of three significant ($P < 0.05$) independent variables had entered into the regression equation.

Use of multiple regression assumes that the relationship between fish populations and habitat variables is linear. Some important relationships may not be linear, however, and nonlinear statistical techniques should be used (Draper and Smith 1981).

To demonstrate, we provide an example, using our data, of treatment effects' on selected habitat variables (Table 3). Habitat differed significantly between old-growth, buffered, and clear-cut reaches. From this analysis, we concluded that clear-cut reaches without buffer strips had less canopy density, pool area, large organic debris volume, and bank stability than old-growth reaches. Reaches with buffer strips had less canopy density than old-growth reaches but had similar pool area, large organic debris volume, and bank stability. Murphy and Hall (1981) and Hawkins et al. (1983) are studies that use similar experimental designs.

Table 3.--Comparison of selected habitat variables, measured in summer, in old-growth, buffered, and clear-cut reaches. Data are means of 18 reaches. Means with asterisks are significantly different ($P \leq 0.05$) from old-growth reaches. Significance based on two-way ANOVA with logging treatment and replication as factors and stream discharge as the covariate.

Habitat variable	Old-growth	Buffered	Clear-cut
Canopy density (%)	74	65*	27*
Pool area (%)	56	55	38*
Total large organic debris volume per m ²	0.76	0.104	0.047*
Stability index	71	76	87*

PRECISION OF METHODS

Sampling methods should obtain valid quantitative results over time under any set of conditions. In field studies, the reproducibility of measurements and their interpretation depend on whether different observers measure habitat characteristics similarly. To determine the precision of two field teams measuring the same habitat characteristics, we divided a test stream into three reaches, and each team sampled each reach.

Generally, the precision of our measurements agreed with findings of Platts et al. (1983). Measurements taken along transects (Table 4) were nearly identical with one exception, Discrepancy existed in distinguishing gravel from small cobbles. Platts et al. (1983) also reported difficulty in separating gravel from small cobbles and attributed it to the similar size of the two substrates. They recommend that the different size classes of rock substrates be embedded in plastic and laid down on the channel for comparison. Mean values for discharge, gradient, undercut bank area, and volume of large organic debris were also similar (Table 4). The qualitative rating of channel stability, which varied by reach, resulted in the same overall rating (good) by both teams (Table 4). The most notable discrepancy between teams was in measuring pool volume (Table 4). Differences in measured pool volume were attributed to the two teams interpreting pool boundaries differently. The differences can be reduced, however, if field teams practice measuring pools before the field season. Perhaps a current meter could be used to detect pool boundaries, because water velocity changes at the transition between habitat types.

SUMMARY

We describe methods used by Auke Bay Laboratory in a study to assess habitat alterations (primarily logging) on small streams in southeastern

Table 4.--Comparison of habitat characteristics in the same three reaches of a stream measured by two different teams. ND = not determined.

Measurements	Team I					Team II				
	Lower	Middle	Upper	\bar{x}	sd	Lower	Middle	Upper	\bar{x}	sd
*Canopy Density	75	93	98	89	12	62	86	95	81	17
Discharge (m ³ /s)	0.12	0.15	0.08	0.12	0.04	0.13	0.16	ND	0.15	0.02
Gradient (%)	1.42	0.75	1.37	1.18	0.37	1.03	0.70	0.80	0.84	0.17
*Wetted Area (m ²)	95.6	100.2	79.9	91.9	10.6	97.7	99.9	81.0	92.9	10.3
*Average depth (cm)	15	15	20	17	3	16	15	19	17	2
*Habitat Types (%)										
Pools	28.5	26.7	40.5	31.9	7.5	35.8	27.1	32.7	31.9	4.4
Riffles	65.6	59.8	32.1	52.5	17.9	56.7	61.5	43.0	53.7	9.6
Glides	5.9	13.5	27.4	15.6	10.9	7.5	11.4	24.3	14.4	8.8
*Substrate types (%)										
Sand	6.2	6.5	7.4	6.7	0.6	6.0	5.5	9.7	7.1	2.3
Gravel	63.0	61.7	72.6	65.8	6.0	67.7	80.4	77.7	75.3	6.7
Small Cobbles	16.4	18.3	13.2	16.0	2.6	10.3	3.2	4.0	5.8	3.9
Cobbles	4.5	0	0.3	1.6	2.5	4.0	1.2	1.3	2.2	1.6
Boulder	8.2	7.8	1.0	5.7	4.1	11.8	7.7	3.7	7.7	4.1
Fine Particulate										
Organic Matter	0	0.8	0	0.3	0.5	0	1.0	0.3	0.4	0.5
Coarse Particulate										
Organic Matter	1.1	4.9	3.7	3.3	1.9	0.2	0.5	2.7	1.1	1.4
Large Organic										
Debris	0.6	0	1.0	0.5	0.5	0	0.5	2.7	1.1	1.4
Pool Volumes (m ³)	9.7	4.8	11.9	8.8	3.6	7.5	3.4	3.6	4.8	2.3
Undercut Bank Area (m ²)	1.0	5.6	9.3	5.3	4.2	1.6	7.5	6.6	5.2	3.2
Volume of large										
Organic Debris (m ³)	0.07	1.03	1.12	0.74	0.58	0.04	0.90	1.05	0.47	0.61
Channel Stability										
Index	84	64	78	75	10	69	52	67	63	9

* Measured along transects.

Alaska. The methodology is a compilation and refinement of methods developed by others and new methods developed by researchers at the Laboratory. Although originally designed for logging studies, many or all of the methods described should provide useful data for assessing the effects of other habitat alterations (e.g., mining and road construction) on stream systems.

For more intensive studies of individual watersheds, our experimental design can be modified by increasing the size or number of reaches. For studies that do not need detailed information, only the following key habitat and fish variables need to be measured:

1. Measurements along transects:

Total surface area of the reach.
Pool:riffle:glide ratios.

2. Stream discharge and gradient.
3. Biomass of algae.
4. Number of pieces of large organic debris in the stream channel.
5. Area of undercut banks.
6. Water temperature.
7. Fish population estimates for key species, including lengths and ages.

Whenever possible, however, all variables included in this paper, and possibly more, should be measured to ensure that all effects are identified.

Although standardized methods are difficult to develop because of natural variation in biota at different locations and different times, we have tried to develop a set of methods that can be repeated over time by different personnel with good precision. The methods described are not perfect and will need refinement. New methods should be developed as knowledge of the habitat requirements of fishes and effects of logging on stream ecosystems increases.

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